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1 Radix-4 decimate in time complex FFT

1.1 Description

This function computes a complex FFT from an input signal. It uses the Radix-4 "Decimate In Time" algorithm and does not perform a calculation "in place" which means that the input buffer has to be different from the output buffer.

1.1.1 Function prototype

void **dspXX_trans_complexfft**(
dspXX_complex_t **vect1*,
dspXX_t **vect2*,
int *nlog*);

where XX corresponds to the number of bits of a basic data element (i.e. 16 or 32).

1.1.2 Arguments

This function takes three parameters: the output buffer, the input buffer and a value corresponding to the size of those buffers.

- The output buffer (vect1) is a pointer on a complex vector of **2^nlog** elements.
- The input buffer (vect2) is a pointer on a real vector of **2^nlog** elements.
- The size argument (nlog) is in fact the base-2-logarithm of the size of the input vector. (nlog∈ [2, 4, 6, …, 28])

1.1.3 Algorithm

Following is the algorithm used to implement the radix-4 DIT complex FFT. The optimized version is based on this algorithm but can differ in certain points due to the instruction set of the target:

```
size = 1 << nlog

FOR r FROM 0 TO size-1 STEP 4 DO
        Butterfly_zero_only_real_and_bit_reversing(vect1, vect2, r)
END

FOR stage FROM 1 TO nlog/2 DO
        m = 4 ^ stage

        FOR r FROM 0 TO size-1 STEP m DO
                Butterfly_zero(vect1, r)
        END

        FOR j FROM 1 TO m / 4 - 1 DO
                Comput_twiddle_factors(e, e2, e3, j / m)

                FOR r FROM 0 TO size-1 STEP m DO
                        Butterfly(vect1, r, j, e, e2, e3)
                END
        END
END
```

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1.1.4 Notes

- **Interruptibility**: the code is interruptible.
- In-place computation is not allowed.
- This function uses a static twiddle factors table raw-coded in the file "*BASIC/TRANSFORMS/dspXX_twiddle_factors.h*". To generate those factors, you can use the script called "tf_gen.sci" and execute it with Scilab.
- To avoid overflowing values, the resulting vector amplitude is scaled by 2^nlog.
- All the vectors have to be 32-bit aligned.

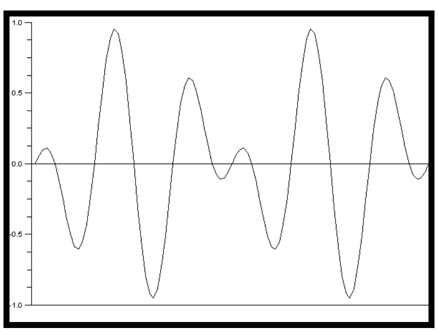
1.2 Benchmark

1.2.1 Benchmark routine

All these functions have been benchmarked on an avr32-uc3a0512 target. The programs have been compiled with avr32-gcc (4.0.2-atmel.1.0.0) with the –O3 optimization option and have been stored in FLASH memory. The fixed-point format used is the Q1.15 format for the 16-bit data and the Q1.31 format for the 32-bit data.

The benchmark process has been performed with the same input signal for all those functions and compared with a reference's signal computed with a mathematic tool using floating point.

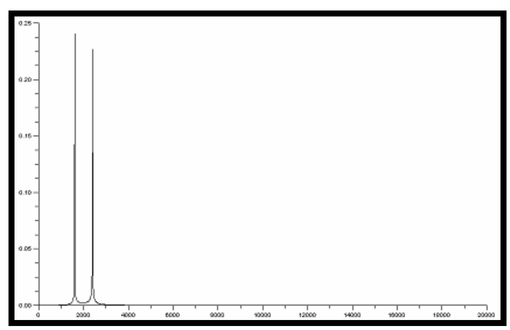
The input signal is a combination of one sine and one cosine. The sine oscillating at 400Hz and the cosine at 2KHz. Those signals have been multiplied and sampled at 40KHz.



Input signal

>

Complex FFT



Signal resulting and formatted (FFT)

1.2.2 Result

Here are tables of the main values of the benchmark results. All those values correspond to the best performances of the functions and are obtained with different compilation options. For more information, please refer to the complete benchmark result table in annexes.

1.2.2.1 16-bit radix-4 D.I.T. complex FFT: generic

Concerned file path: */BASIC/TRANSFORMS/dsp16_complex_fft_generic.c*

	Lowest cycle count	Fastest computation at 60 MHz	Lowest Error		Lowest Algorithm's size in memory
			Amplitude average	Max. amplitude	
64-points	6,296	108.2us	1.58e-5	6.53e-5	1.1 Kbytes
256-points	33,723	578.0us	1.69e-5	8.80e-5	1.3 Kbytes
1024-points	169,006	2.90ms	1.67e-5	12.31e-4	2.0 Kbytes
4096-points	812,321	13.90ms	1.52e-5	14.60e-4	5.0 Kbytes

More details on Table 1.1.1 in annexes

1.2.2.2 16-bit radix-4 D.I.T. complex FFT: avr32-uc3 optimized

Concerned file path: */BASIC/TRANSFORMS/dsp16_complex_fft_avr32uc3.c*

	Lowest cycle count	Fastest computation at 60 MHz	Lowest Error		Lowest Algorithm's size in memory
			Amplitude average	Max. amplitude	
64-points	2,611	44.4 us	1.63e-5	6.53e-5	710 bytes
256-points	13,661	232.2 us	1.68e-5	7.46e-5	902 bytes
1024-points	67,671	1.15 ms	1.69e-5	1.02e-4	1.6 Kbytes
4096-points	322,897	5.49 ms	1.58e-5	1.18e-4	4.6 Kbytes

Warning: this function is only compatible with Q1.15 numbers.

Note: this function needs 72 bytes of memory for the stack.

More details on Table 1.1.2 in annexes

1.2.2.3 32-bit radix-4 D.I.T. complex FFT: generic

Concerned file path: */BASIC/TRANSFORMS/dsp32_complex_fft_generic.c*

	Lowest cycle count	Fastest computation at 60 MHz	Lowest Error		Lowest Algorithm's size in memory
			Amplitude average	Max. amplitude	
64-points	13,206	225.2us	6.0e-10	5.7e-9	2.0 Kbytes
256-points	74,297	1.27us	3.0e-10	4.8e-9	2.4 Kbytes
1024-points	383,212	6.53ms	3.0e-10	6.1e-9	3.9 Kbytes

More details on Table 1.2.1 in annexes

2 Convolution

2.1 Description

This function performs a linear convolution between two discrete sequences.

2.1.1 Function prototype

void **dspXX_vect_conv**(
    dspXX_t **vect1*,
    dspXX_t **vect2*,
    int vect2_*size*,
    dspXX_t **vect3*,
    int *vect3_size*);

where XX corresponds to the number of bits of a basic data element (i.e. 16 or 32).

2.1.2 Arguments

This function takes five parameters: the output buffer, the two discrete sequences and their respective sizes.

- The output buffer (vect1) is a pointer on a real vector of **(vect2_size + vect3_size - 1)** elements.
- The first input buffer (vect2) is a pointer on a real vector of **vect2_size** elements.
- The first size argument (vect2_size) is the length of the first input buffer (vect2_size∈ [8, 9, 10, …]).
- The second input buffer (vect3) is a pointer on a real vector of **vect3_size** elements.
- The second size argument (vect3_size) is the length of the second input buffer (vect3_size ∈ [8, 9, 10, …]).

2.1.3 Requirements

This function requires 3 modules:

Module name	Function name	Concerned file path
Zero Padding	dspXX_vect_zeropad	*/BASIC/VECTORS/zero_padding.c*
Copy	dspXX_vect_copy	*/BASIC/VECTORS/copy.c*
Partial Convolution	dspXX_vect_convpart	*/BASIC/VECTORS/convolution_partial.c*

The output buffer of the function has to have at least a length of **N + 2*M – 2** elements because of intern computations, where N is the length of the largest input buffer and M, the length of the smallest input buffer.

2.1.4 Algorithm

Following is the algorithm used to implement the convolution product. The optimized version is based on this algorithm but can differ in certain points due to the instruction set of the target:

IF vect2_size **>=** vect3_size **THEN**

vect1 =

0 0 0 0 … 0 0 0 0	vect2	0 0 0 0 … 0 0 0 0
vect3_size – 1	*vect2_size*	*vect3_size – 1*

Partial_convolution(vect1**,** vect1**,** vect2_size + 2*(vect3_size – 1)**,** vect3**,** vect3_size)

ELSE

vect1 =

0 0 0 0 … 0 0 0 0	vect3	0 0 0 0 … 0 0 0 0
vect2_size – 1	*vect3_size*	*vect2_size – 1*

Partial_convolution(vect1**,** vect1**,** vect3_size + 2*(vect2_size – 1)**,** vect2**,** vect2_size)

END

2.1.5 Notes

- **Interruptibility**: the code is interruptible.
- Due to its implementation, the dsp16-avr32-uc3 optimized version of the FIR requires a length of 4*m elements for the largest input discrete sequence and the output buffer (vect1) has to have a length of 4*n elements to avoid overflows.
- The input discrete sequences have to be scaled to avoid overflowing values.
- All the vectors have to be 32-bit aligned.

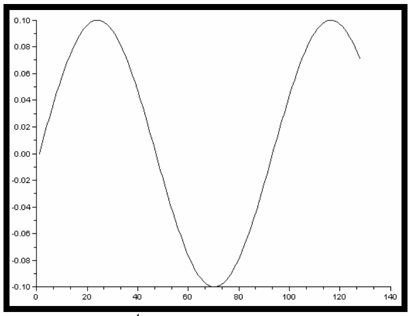
2.2 Benchmark

2.2.1 Benchmark routine

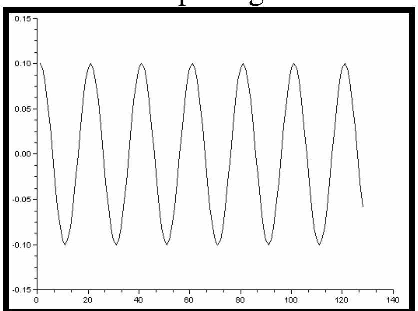
All these functions have been benchmarked on an avr32-uc3a0512 target. The programs have been compiled with avr32-gcc (4.1.2-atmel.1.0.0) with the –O3 optimization option and have been stored in FLASH memory. The fixed-point format used is the Q1.15 format for the 16-bit data and the Q1.31 format for the 32-bit data.

The benchmark process has been performed with the same input signal and impulse response for all those functions and compared with a reference's signal computed with a mathematic tool using floating point.

The first input signal is a sine oscillating at 433Hz and the second input signal is a cosine oscillating at 2KHz. Those signals are sampled at 40KHz.

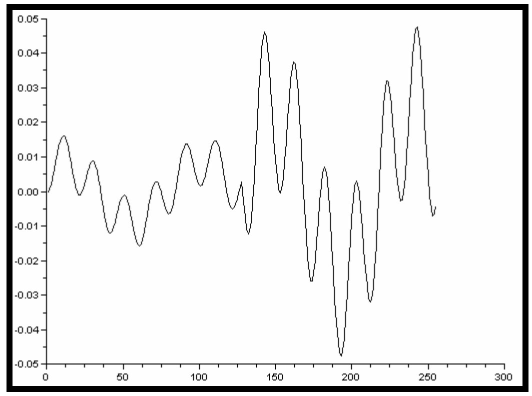


1st input signal



2nd input signal

FIR filter



Resulting signal

2.2.2 Result

Here are tables of the main values of the benchmark results. All those values correspond to the best performances of the functions and are obtained with different compilation options. For more information, please refer to the complete benchmark result table in annexes.

Concerned file path: */BASIC/VECTORS/convolution.c*

2.2.2.1 16-bit Convolution: generic

Algorithm's size in memory: 2.2 Kbytes.
Length of the first input signal: 64 elements.

	Lowest cycle count	**Fastest computation at 60 MHz**	**Lowest Error**	
			Amplitude average	Max. amplitude
32-points	23,524	408.5us	2.0e-5	4.5e-5
64-points	57,757	1.00ms	1.8e-5	4.7e-5
128-points	86,752	1.50ms	1.8e-5	4.4e-5
256-points	144,736	2.51ms	1.5e-5	4.8e-5

More details on Table 2.1.1 in annexes

2.2.2.2 16-bit Convolution: avr32-uc3 optimized

Algorithm's size in memory: 950 bytes.
Length of the first input signal: 64 elements.

	Lowest cycle count	Fastest computation at 60 MHz	Lowest Error	
			Amplitude average	Max. amplitude
32-points	8,248	151.2us	2.0e-5	4.5e-5
64-points	19,087	349.1us	1.8e-5	4.7e-5
128-points	28,532	521.8us	1.8e-5	4.4e-5
256-points	47,412	866.9us	1.5e-5	4.8e-5

More details on Table 2.1.2 in annexes

2.2.2.3 32-bit Convolution: generic

Algorithm's size in memory: 3.3 Kbytes.
Length of the first input signal: 64 elements.

	Lowest cycle count	Fastest computation at 60 MHz	Lowest Error	
			Amplitude average	Max. amplitude
32-points	42,572	729.8us	0.4e-9	2.1e-9
64-points	109,179	1.87ms	0.4e-9	1.7e-9
128-points	163,968	2.81ms	0.5e-9	1.6e-9
256-points	273,536	4.69ms	0.6e-9	2.7e-9

More details on Table 2.2.1 in annexes

2.2.2.4 32-bit Convolution: avr32-uc3 optimized

Algorithm's size in memory: 1.5 Kbytes.
Length of the first input signal: 64 elements.

	Lowest cycle count	Fastest computation at 60 MHz	Lowest Error	
			Amplitude average	Max. amplitude
32-points	19,958	340.2us	0.5e-9	2.1e-9
64-points	50,501	860.4us	0.5e-9	1.7e-9
128-points	75,722	1.29ms	0.6e-9	2.4e-9
256-points	126,154	2.15ms	0.7e-9	2.7e-9

More details on Table 2.2.2 in annexes

3 FIR Filter *(alias Partial Convolution)*

3.1 Description

This function computes a real FIR filter using the impulse response of the desire filter onto a fixed-length signal.

3.1.1 Function prototype

void **dspXX_filt_fir**(
dspXX_t **vect1*,
dspXX_t **vect2*,
int *size*,
dspXX_t **h*,
int *h_size*);

void **dspXX_vect_convpart**(
dspXX_t **vect1*,
dspXX_t **vect2*,
int vect2_*size*,
dspXX_t **vect3*,
int *vect3_size*);

where XX corresponds to the number of bits of a basic data element (i.e. 16 or 32).

3.1.2 Arguments

This function takes five parameters: the output buffer, the input buffer, its size, the impulse response of the filter and its size.

- The output buffer (vect1) is a pointer on a real vector of **(size - h_size + 1)** elements.
- The input buffer (vect2) is a pointer on a real vector of **size** elements.
- The size argument (size) is the length of the input buffer (size∈ [4, 8, 12, …]).
- The impulse response of the filter (h) is a pointer on a real vector of **h_size** elements.
- The size argument (h_size) is the length of the impulse response of the filter (h_size∈ [8, 9, 10, …]).

3.1.3 Requirements

This function requires one module:

Module name	Function name	Concerned file path
Partial Convolution	dspXX_vect_convpart	*/BASIC/VECTORS/convolution_partial.c*

3.1.4 Algorithm

Following is the algorithm used to implement the FIR filter. The optimized version is based on this algorithm but can differ in certain points due to the instruction set of the target:

```
FOR j FROM 0 TO size - h_size + 1 DO
    sum = 0

    FOR i FROM 0 TO h_size DO
        sum += vect2[i] * h[h_size - i - 1]
    END

    vect1[j] = sum >> DSPXX_QB
END
```

3.1.5 Notes

- **Interruptibility**: the code is interruptible.
- Due to its implementation, for the dsp16-avr32-uc3 optimized version of the FIR, the output buffer (vect1) has to have a length of 4*n elements to avoid overflows.
- The impulse response of the filter has to be scaled to avoid overflowing values.
- All the vectors have to be 32-bit aligned.

3.2 Benchmark

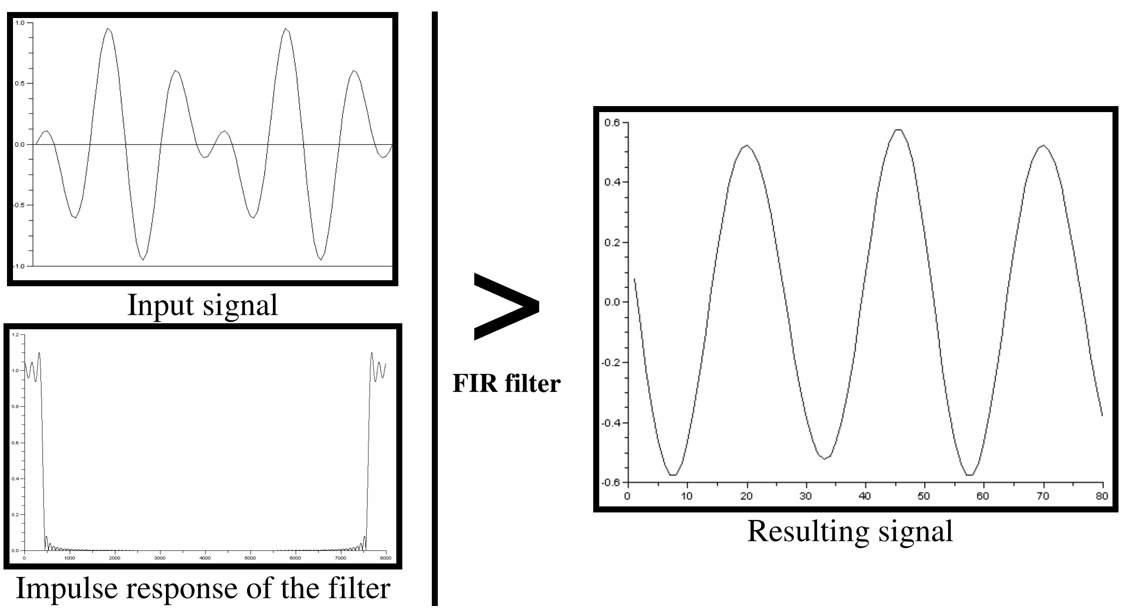
3.2.1 Benchmark routine

All these functions have been benchmarked on an avr32-uc3a0512 target. The programs have been compiled with avr32-gcc (4.1.2-atmel.1.0.0) with the –O3 optimization option and have been stored in FLASH memory. The fixed-point format used is the Q1.15 format for the 16-bit data and the Q1.31 format for the 32-bit data.

The benchmark process has been performed with the same input signal and impulse response for all those functions and compared with a reference's signal computed with a mathematic tool using floating point.

The input signal is a combination of one sine and one cosine. The sine oscillating at 400Hz and the cosine at 2KHz. Those signals have been multiplied and sampled at 40KHz.

The impulse response describes a low-pass filter with a cutoff frequency equal to 400Hz.



3.2.2 Result

Here are tables of the main values of the benchmark results. All those values correspond to the best performances of the functions and are obtained with different compilation options. For more information, please refer to the complete benchmark result table in annexes.

3.2.2.1 16-bit FIR filter: generic

Concerned file path: */BASIC/VECTORS/dsp16_convpart_generic.c*
Algorithm's size in memory: 2.0 Kbytes.
Number of Taps: 24.

	Lowest cycle count	Fastest computation at 60 MHz	Lowest Error	
			Amplitude average	Max. amplitude
64-points	7,424	128.0us	2.27e-5	9.46e-5
256-points	41,793	720.0us	2.22e-5	9.46e-5
512-points	87,617	1.51ms	2.23e-5	9.46e-5
1024-points	179,265	3.09ms	2.21e-5	9.46e-5

More details on Table 3.1.1 in annexes

3.2.2.2 16-bit FIR filter: avr32-uc3 optimized

Concerned file path: */BASIC/VECTORS/dsp16_convpart_avr32uc3.c*
Algorithm's size in memory: 770 bytes.
Number of Taps: 24.

	Lowest cycle count	Fastest computation at 60 MHz	Lowest Error	
			Amplitude average	Max. amplitude
64-points	2,439	44.3us	2.27e-5	9.46e-5
256-points	12,712	230.7us	2.22e-5	9.46e-5
512-points	26,408	479.2us	2.23e-5	9.46e-5
1024-points	53,800	976.3us	2.21e-5	9.46e-5

More details on Table 3.1.2 in annexes

3.2.2.3 32-bit FIR filter: generic

Concerned file path: */BASIC/VECTORS/dsp32_convpart_generic.c*
Algorithm's size in memory: 3.1 Kbytes.
Number of Taps: 24.

	Lowest cycle count	Fastest computation at 60 MHz	Lowest Error	
			Amplitude average	Max. amplitude
64-points	13,984	239.4us	2.1e-9	1.24e-8
256-points	79,073	1.35ms	2.3e-9	1.74e-8
512-points	165,857	2.84ms	2.6e-9	2.31e-8
1024-points	339,425	5.81ms	3.7e-9	2.84e-8

More details on Table 3.2.1 in annexes

3.2.2.4 32-bit FIR filter: avr32-uc3 optimized

Concerned file path: */BASIC/VECTORS/dsp32_convpart_avr32uc3.c*
Algorithm's size in memory: 1.3 Kbytes.
Number of Taps: 24.

	Lowest cycle count	**Fastest computation at 60 MHz**	**Lowest Error**	
			Amplitude average	Max. amplitude
64-points	6,479	110.2us	2.1e-9	1.24e-8
256-points	36,432	619.0us	2.3e-9	1.24e-8
512-points	76,368	1.30ms	2.6e-9	2.31e-8
1024-points	156,240	2.65ms	3.7e-9	2.84e-8

More details on Table 3.2.2 in annexes

4 IIR Filter

4.1 Description

This function computes a real IIR filter using the impulse response of the desire filter onto a fixed-length signal.

4.1.1 Function prototype

void **dspXX_filt_iir**(
dspXX_t **vect1*,
dspXX_t **vect2*,
int *size*,
dspXX_t **num*,
int *num_size,*
dspXX_t **den*,
int *den_size,*
int *prediv*);

where XX corresponds to the number of bits of a basic data element (i.e. 16 or 32).

4.1.2 Arguments

This function takes five parameters: the output buffer, the input buffer, its size, the coefficients of the filter, theirs sizes and a coefficient's predivisor.

- The output buffer (vect1) is a pointer on a real vector of **(size - num_size + 1)** elements.
- The input buffer (vect2) is a pointer on a real vector of **size** elements.
- The size argument (size) is the length of the input buffer (size ∈ [4, 5, 6, 7, …]).
- The numerator's coefficients argument of the filter (num) is a pointer on a real vector of **num_size** elements.
- The size argument (num_size) is the length of the numerator's coefficients of the filter (num_size∈ [1, 2, 3, …]).
- The denominator's coefficients argument of the filter (den) is a pointer on a real vector of **den_size** elements.
- The size argument (den_size) is the length of the denominator's coefficients of the filter (den_size∈ [1, 2, 3, …]).
- The predivisor (prediv) is used to scale down the denominator's coefficients of the filter in order to avoid overflow values. So when you use this feature, you have to prescale manually the denominator's coefficients by 2^prediv else leave this field to 0.

4.1.3 Algorithm

Following is the algorithm used to implement the IIR filter. The optimized version is based on this algorithm but can differ in certain points due to the instruction set of the target:

```
// Initialization of the vect1 coefficients
FOR n FROM 0 TO den_size - 1 DO
        sum1 = 0
        FOR m FROM 0 TO num_size - 1 DO
                sum1 += num[m] * vect2[n + num_size - m - 1]
        END

        sum2 = 0
        FOR m FROM 1 TO n DO
                sum2 += den[m] * vect1[n - m]
        END

        vect1[n] = (sum1 – (sum2 << prediv)) >> DSPXX_QB
END

FOR n FROM n TO size – num_size DO
        sum1 = 0
        FOR m FROM 0 TO num_size - 1 DO
                sum1 += num[m] * vect2[n + num_size - m - 1]
        END

        sum2 = 0
        FOR m FROM 1 TO den_size - 1 DO
                sum2 += den[m] * vect1[n - m]
        END

        vect1[n] = (sum1 – (sum2 << prediv)) >> DSPXX_QB
END
```

4.1.4 Notes

- **Interruptibility**: the code is interruptible.
- Due to its implementation, for the dsp16-avr32-uc3 optimized version of the FIR, the output buffer (vect1) has to have a length of 4*n elements to avoid overflows.
- The impulse response of the filter has to be scaled to avoid overflowing values.
- All the vectors have to be 32-bit aligned.
- The first denominator's coefficient have to be equal to 1 / (2^prediv).
- The predivisor (prediv) must be lower or equals to the constant DSPXX_QB.

4.2 Benchmark

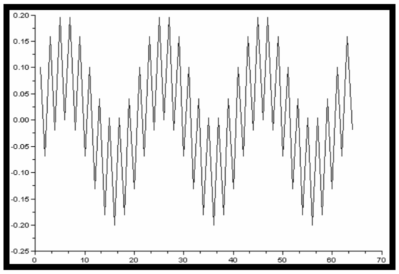
4.2.1 Benchmark routine

All these functions have been benchmarked on an avr32-uc3a0512 target. The programs have been compiled with avr32-gcc (4.1.2-atmel.1.0.0) with the –O3 optimization option and have been stored in FLASH memory. The fixed-point format used is the Q1.15 format for the 16-bit data and the Q1.31 format for the 32-bit data.

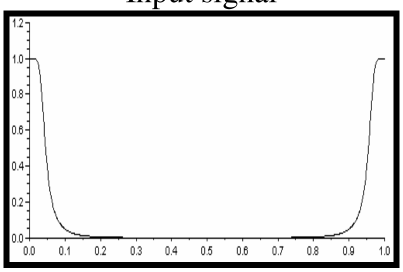
The benchmark process has been performed with the same input signal and impulse response for all those functions and compared with a reference's signal computed with a mathematic tool using floating point.

The input signal is a combination of one sine and one cosine. The sine oscillating at 400Hz and the cosine at 4KHz. Those signals have been added together and sampled at 8KHz.

The filter used is a low-pass Butterworth filter with a cutoff frequency equal to 2KHz.

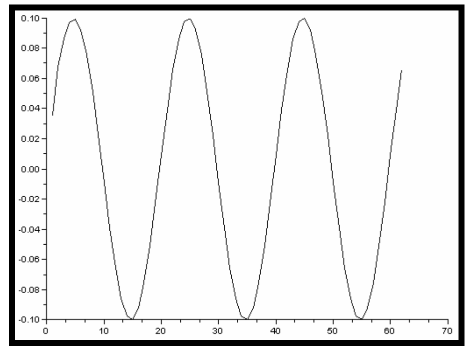


Input signal



Filter's module

IIR filter



Resulting signal

4.2.2 Result

Here are tables of the main values of the benchmark results. All those values correspond to the best performances of the functions and are obtained with different compilation options. For more information, please refer to the complete benchmark result table in annexes.

4.2.2.1 16-bit IIR filter: generic

Concerned file path: */BASIC/FILTERING/dsp16_iir_generic.c*

Algorithm's size in memory: 266 bytes.

Order of the filter: 7

	Lowest cycle count	**Fastest computation at 60 MHz**	**Lowest Error**	
			Amplitude average	Max. amplitude
72-points	11,469	213.4us	1.40e-5	4.30e-5
256-points	44,591	829.8us	1.40e-5	4.30e-5
512-points	90,671	1.69ms	1.40e-5	4.30e-5
1024-points	182,831	3.40ms	1.40e-5	4.30e-5

More details on Table 4.1.1 in annexes

4.2.2.2 16-bit IIR filter: avr32-uc3 optimized

Concerned file path: */BASIC/FILTERING/dsp16_iir_avr32uc3.c*
Algorithm's size in memory: 1.0 Kbytes (size optimization), 3.1 Kbytes (speed optimization).
Order of the filter: 7

	Lowest cycle count	**Fastest computation at 60 MHz**	**Lowest Error**	
			Amplitude average	Max. amplitude
72-points	4,332	78.0us	1.90e-5	6.90e-5
256-points	15,006	270.5us	1.70e-5	6.90e-5
512-points	29,854	538.2us	1.70e-5	6.90e-5
1024-points	59,550	1.07ms	1.70e-5	6.90e-5

More details on Table 4.1.2 in annexes

4.2.2.3 32-bit IIR filter: generic

Concerned file path: */BASIC/FILTERING/dsp32_iir_generic.c*
Algorithm's size in memory: 400 bytes.
Order of the filter: 7

	Lowest cycle count	**Fastest computation at 60 MHz**	**Lowest Error**	
			Amplitude average	Max. amplitude
72-points	14,517	265.4us	1.50e-9	7.00e-9
256-points	56,471	1.03ms	1.50e-9	7.00e-9
512-points	114,839	2.10ms	1.50e-9	7.00e-9
1024-points	231,575	4.23ms	1.50e-9	7.00e-9

More details on Table 4.2.1 in annexes

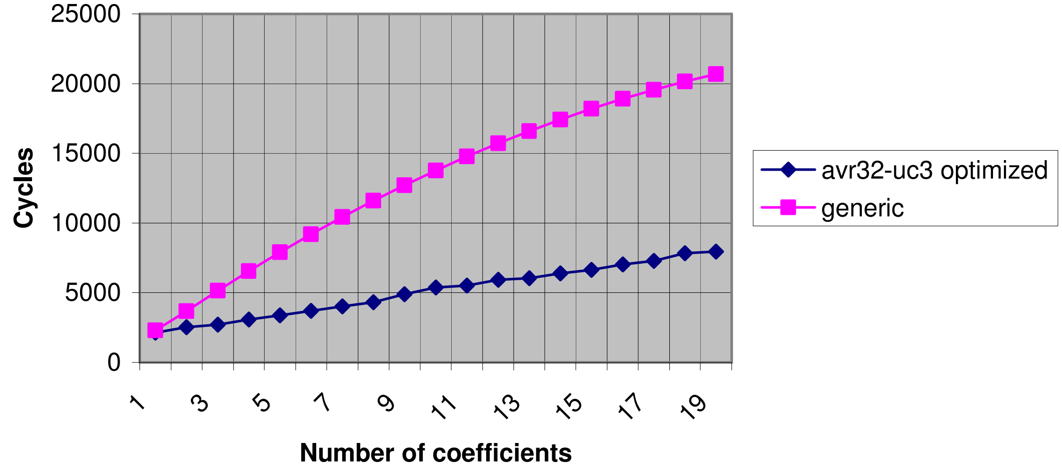
4.2.2.4 32-bit IIR filter: avr32-uc3 optimized

Concerned file path: */BASIC/FILTERING/dsp32_iir_avr32uc3.c*
Algorithm's size in memory: 3.0 Kbytes.
Order of the filter: 7

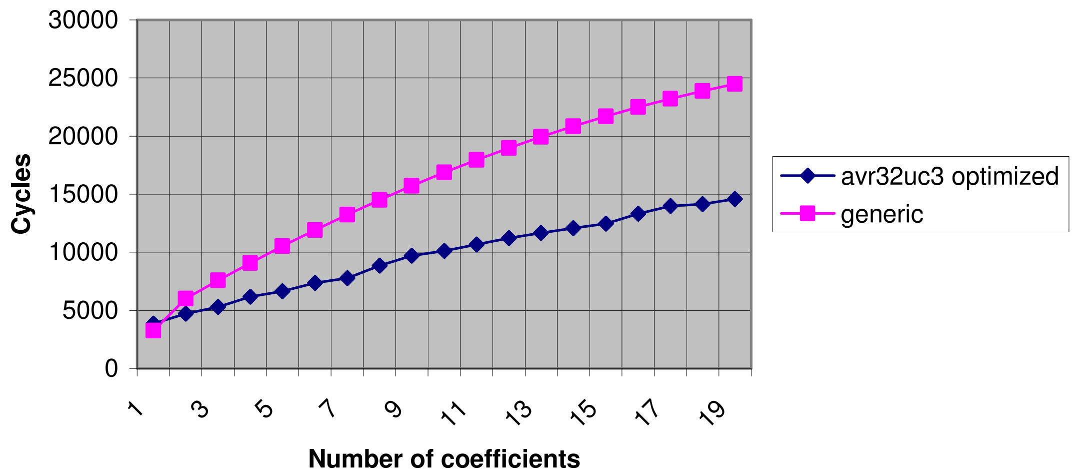
	Lowest cycle count	**Fastest computation at 60 MHz**	**Lowest Error**	
			Amplitude average	Max. amplitude
72-points	8,859	153.9us	1.50e-9	7.00e-9
256-points	33,333	577.1us	1.50e-9	7.00e-9
512-points	67,381	1.17ms	1.60e-9	7.00e-9
1024-points	135,477	2.34ms	1.60e-9	7.00e-9

More details on Table 4.2.2 in annexes

Benchmark results for the 16-bit version (with speed optimization)
The benchmark has been performed on a 72-element input signal.



Benchmark results for the 32-bit version (with speed optimization)
The benchmark has been performed on a 72-element input signal.



Remark: the number of coefficients corresponds to a filter which order is equal to "Number of coefficients" – 1.

5 Annexes

TABLE 1.1.1 - BENCHMARK OF 16-BIT RADIX-4 D.I.T. COMPLEX FFT: GENERIC

	Optimization	**T.F.T.* in SRAM** *(cycles)* wait-state **0** *at 30MHz*	**T.F.T.* in SRAM** *(cycles)* wait-state **1** *at 60MHz*	**T.F.T.* in FLASH** *(cycles)* wait-state **0** *at 30MHz*	**T.F.T.* in FLASH** *(cycles)* wait-state **1** *at 60MHz*	**Error** *Amplitude average ($x10^{-5}$)*	**Error** *Max. amplitude ($x10^{-5}$)*	**Algorithm's size in memory** *(bytes) (code size + T.F.T.* size)*
64-point	(0)	**6,296** (209.9us)	6,489 **(108.2us)**	6,640 (221.3us)	7,012 (116.9us)	2.98	15.63	1K *(840 + 194)*
	(1)	6,343 (211.4us)	6,538 (109.0us)	6,777 (225.9us)	7,167 (119.5us)	**1.58**	**6.53**	1K *(844 + 194)*
	(2)	6,666 (222.2us)	6,959 (116.0us)	7,092 (236.4us)	7,546 (125.8us)	2.98	15.63	**1.1K** *(1032 + 66)*
	(3)	6,747 (224.9us)	6,996 (116.6us)	7,101 (236.7us)	7,536 (125.6us)	1.58	6.53	1K *(984 + 66)*
256-point	(0)	**33,723** (1124.1us)	34,682 **(578.0us)**	35,265 (1175.5us)	37,033 (617.2us)	3.02	21.92	1.6K *(840 + 770)*
	(1)	34,041 (1134.7us)	35,003 (583.4us)	35,988 (1199.6us)	37,836 (630.6us)	**1.69**	**8.80**	1.6K *(844 + 770)*
	(2)	35,304 (1176.8us)	36,675 (611.3us)	37,194 (1239.8us)	39,294 (654.9us)	3.02	21.92	**1.3K** *(1032 + 258)*
	(3)	35,,826 (1194.2us)	37,032 (617.2us)	37,419 (1247.3us)	39,453 (657.6us)	1.69	8.80	1.2K *(984 + 258)*
1024-point	(0)	**169,006** (5.63ms)	173,611 **(2.90ms)**	175,394 (5.85ms)	183,358 (3.06ms)	3.04	25.01	3.8K *(840 + 3K)*
	(1)	170,795 (5.69ms)	175,404 (2.92ms)	178,863 (5.96ms)	187,161 (3.12ms)	**1.67**	**12.31**	3.8K *(844 + 3K)*
	(2)	175,446 (5.85ms)	181,703 (3.03ms)	183,248 (6.11ms)	192,530 (3.21ms)	3.04	25.01	**2K** *(1032 + 1K)*
	(3)	178,153 (5.94ms)	183,772 (3.06ms)	184,761 (6.16ms)	193,802 (3.23ms)	1.67	12.31	2K *(984 + 1K)*
4096-point	(0)	**812,321** (27.08ms)	833,820 **(13.90ms)**	838,147 (27.94ms)	873,235 (14.55ms)	3.09	32.90	12.8K *(840 + 12K)*
	(1)	821,533 (27.38ms)	843,037 (14.05ms)	854,154 (28.47ms)	890,598 (14.84ms)	**1.52**	**14.60**	12.8K *(844 + 12K)*
	(2)	838,212 (27.94ms)	866,315 (14.44ms)	869,718 (28.99ms)	910,054 (15.17ms)	3.09	32.90	**5K** *(1032 + 4K)*
	(3)	851,232 (28.37ms)	876,816 (14.61ms)	877,959 (29.27ms)	917,367 (15.29ms)	1.52	14.60	5K *(984 + 4K)*

*: Twiddle Factors Table.
(0): Algorithmic optimized for **speed.**
(1): Algorithmic optimized for **accuracy.**
(2): Algorithmic optimized for **size**.
(3): Algorithmic optimized for **size** and **accuracy**.

TABLE 1.1.2 - BENCHMARK OF 16-BIT RADIX-4 D.I.T. COMPLEX FFT: AVR32-UC3 OPTIMIZED

	Optimization	**T.F.T.* in SRAM** *(cycles)*		**T.F.T.* in FLASH** *(cycles)*		**Error**		**Algorithm's size in memory** *(bytes)* *(code size + T.F.T.* size)*
		wait-state		wait-state		*Amplitude average* $(x10^{-5})$	*Max. amplitude* $(x10^{-5})$	
		0 *at 30MHz*	**1** *at 60MHz*	**0** *at 30MHz*	**1** *at 60MHz*			
64-point	(0)	**2,611** (87.0us)	2,661 **(44.4us)**	2,753 (91.8us)	2,877 (48.0us)	3.00	10.04	894 *(700 + 194)*
	(1)	2,951 (98.4us)	2,999 (50.0us)	3,097 (103.2us)	3,265 (54.4us)	**1.63**	**6.53**	774 *(580 + 194)*
	(2)	2,833 (94.4us)	2,912 (48.5us)	3,027 (100.9us)	3,221 (53.7us)	2.93	10.04	**710** *(644 + 66)*
	(3)	3,206 (106.9us)	3,311 (55.2us)	3,458 (115.3us)	3,683 (61.4us)	1.63	6.53	766 *(700 + 66)*
256-point	(0)	**13,661** (455.4us)	13,932 **(232.2us)**	14,306 (476.9us)	14,904 (248.4us)	2.78	13.86	1.4K *(700 + 770)*
	(1)	15,777 (525.9us)	16,033 (267.2us)	16,428 (547.6us)	17,242 (287.4us)	**1.68**	**7.46**	1.3K *(580 + 770)*
	(2)	14,651 (488.4us)	15,056 (250.9us)	15,527 (517.6us)	16,442 (274.0us)	2.87	15.82	**902** *(644 + 258)*
	(3)	16,916 (563.9us)	17,469 (291.2us)	18,041 (601.4us)	19,152 (319.2us)	1.68	7.46	958 *(700 + 258)*
1024-point	(0)	**67,671** (2.26ms)	69,027 **(1.15ms)**	70,355 (2.35ms)	73,059 (1.22ms)	2.84	19.33	3.7K *(700 + 3K)*
	(1)	79,195 (2.64ms)	80,475 (1.34ms)	81,887 (2.73ms)	85,507 (1.43ms)	**1.69**	**10.23**	3.6K *(580 + 3K)*
	(2)	71,765 (2.39ms)	73,680 (1.23ms)	75,403 (2.51ms)	79,423 (1.32ms)	2.86	19.33	**1.6K** *(644 + 1K)*
	(3)	83,906 (2.80ms)	86,635 (1.44ms)	88,560 (2.95ms)	93,629 (1.56ms)	1.69	10.23	1.7K *(700 + 1K)*
4096-point	(0)	**322,897** (10.76ms)	329,370 **(5.49ms)**	333,764 (11.13ms)	345,678 (5.76ms)	2.80	23.69	12.7K *(700 + 12K)*
	(1)	381,269 (12.71ms)	387,413 (6.46ms)	392,146 (13.07ms)	407,788 (6.80ms)	**1.58**	**11.84**	12.6K *(580 + 12K)*
	(2)	339,439 (11.31ms)	348,176 (5.80ms)	354,159 (11.81ms)	371,396 (6.19ms)	2.81	23.69	**4.6K** *(644 + 4K)*
	(3)	400,304 (13.34ms)	413,273 (6.89ms)	419,111 (13.97ms)	441,578 (7.36ms)	1.58	11.84	4.7K *(700 + 4K)*

*: Twiddle Factors Table.
(0): Algorithmic optimized for **speed.**
(1): Algorithmic optimized for **accuracy.**
(2): Algorithmic optimized for **size.**
(3): Algorithmic optimized for **size** and **accuracy.**

TABLE 1.2.1 - BENCHMARK OF 32-BIT RADIX-4 D.I.T. COMPLEX FFT: GENERIC

	Optimization	**T.F.T.* in SRAM** *(cycles)*		**T.F.T.* in FLASH** *(cycles)*		**Error**		**Algorithm's size in memory** *(bytes)* *(code size + T.F.T.* size)*
		wait-state		wait-state		*Amplitude average* $(x10^{-9})$	*Max. amplitude* $(x10^{-9})$	
		0 *at 30MHz*	**1** *at 60MHz*	**0** *at 30MHz*	**1** *at 60MHz*			
64-point	(0)	**13,206** (440.2us)	13,509 **(225.2us)**	13,580 (452.7us)	14,063 (234.4us)	0.70	5.70	2.2K *(1816 + 392)*
	(1)	15,323 (510.8us)	15,659 (261.0us)	15,627 (520.9us)	16,113 (268.6us)	**0.60**	**5.70**	2.4K *(2112 + 392)*
	(2)	13,622 (454.1us)	14,011 (233.5us)	13,938 (464.6us)	14,497 (241.6us)	0.70	5.70	**2.0K** *(1952 + 136)*
	(3)	15,714 (523.8us)	16,245 (270.8us)	16,058 (535.3us)	16,805 (280.1us)	0.60	5.70	2.3K *(2248 + 136)*
256-point	(0)	**74,297** (2.48ms)	75,940 **(1.27ms)**	75,992 (2.53ms)	78,445 (1.31ms)	0.50	4.80	3.3K *(1816 + 1.5K)*
	(1)	87,791 (2.93ms)	89,605 (1.49ms)	89,165 (2.97ms)	91,636 (1.53ms)	**0.30**	**4.80**	3.6K *(2112 + 1.5K)*
	(2)	76,136 (2.54ms)	78,160 (1.30ms)	77,537 (2.58ms)	80,329 (1.34ms)	0.50	4.80	**2.4K** *(1952 + 520)*
	(3)	89,543 (2.98ms)	92,446 (1.54ms)	91,058 (3.04ms)	94,978 (1.59ms)	0.30	4.80	2.7K *(2248 + 520)*
1024-point	(0)	**383,212** (12.77ms)	391,715 **(6.53ms)**	390,260 (13.01ms)	402,123 (6.70ms)	0.50	8.80	7.8K *(1816 + 6K)*
	(1)	457,571 (15.25ms)	466,815 (7.78ms)	463,279 (15.44ms)	475,223 (7.92ms)	**0.30**	**6.10**	8.1K *(2112 + 6K)*
	(2)	390,794 (13.03ms)	400,869 (6.68ms)	396,576 (13.22ms)	409,841 (6.83ms)	0.50	8.80	**3.9K** *(1952 + 2K)*
	(3)	464,988 (15.50ms)	479,847 (8.00ms)	471,226 (15.71ms)	490,367 (8.17ms)	0.30	6.10	4.2K *(2248 + 2K)*

*: Twiddle Factors Table.
(0): Algorithmic optimized for **speed.**
(1): Algorithmic optimized for **accuracy.**
(2): Algorithmic optimized for **size.**
(3): Algorithmic optimized for **size** and **accuracy.**

TABLE 2.1.1 - BENCHMARK OF 16-BIT CONVOLUTION: GENERIC

1st input signal	2nd input signal	Execution time (cycles) wait-state **0** *at 30MHz*	Execution time (cycles) wait-state **1** *at 60MHz*	Error: *Amplitude average ($x10^{-5}$)*	Error: *Max. amplitude ($x10^{-5}$)*
32-point	**32-points**	**15,681** (522.7us)	16,344 (**272.4us**)	1.60	3.90
	64-points	**23,524** (784.1us)	24,508 (**408.5us**)	2.00	4.50
	128-points	**39,204** (1.31ms)	40,830 (**680.5us**)	1.90	4.50
	256-points	**70,564** (2.35ms)	73,470 (**1.22ms**)	1.70	4.10
64-point	**64-points**	**57,757** (1.93ms)	60,084 (**1.00ms**)	1.80	4.70
	128-points	**86,752** (2.89ms)	90,234 (**1.50ms**)	1.80	4.40
	256-points	**144,736** (4.82ms)	150,522 (**2.51ms**)	1.50	4.80
128-point	**128-points**	**221,780** (7.39ms)	230,512 (**3.84ms**)	1.80	5.30
	256-points	**333,018** (11.10ms)	346,097 (**5.77ms**)	1.70	5.00
256-point	**256-points**	**869,316** (28.98ms)	903,136 (**15.05ms**)	1.70	5.40

TABLE 2.1.2 - BENCHMARK OF 16-BIT CONVOLUTION: AVR32-UC3 OPTIMIZED

1st input signal	2nd input signal	Execution time (cycles) wait-state **0** *at 30MHz*	Execution time (cycles) wait-state **1** *at 60MHz*	Error: *Amplitude average ($x10^{-5}$)*	Error: *Max. amplitude ($x10^{-5}$)*
32-point	**32-points**	**5,571** (185.7us)	6,127 (**102.1us**)	1.60	3.90
	64-points	**8,248** (274.9us)	9,070 (**151.2us**)	2.00	4.50
	128-points	**13,592** (453.1us)	14,944 (**249.1us**)	1.90	4.50
	256-points	**24,280** (809.3us)	26,688 (**444.8us**)	1.70	4.10
64-point	**64-points**	**19,087** (636.2us)	20,947 (**349.1us**)	1.80	4.70
	128-points	**28,532** (951.1us)	31,308 (**521.8us**)	1.80	4.40
	256-points	**47,412** (1.58ms)	52,012 (**866.9us**)	1.50	4.80
128-point	**128-points**	**70,694** (2.36ms)	77,471 (**1.29ms**)	1.80	5.30
	256-points	**105,966** (3.53ms)	116,099 (**1.93ms**)	1.70	5.00
256-point	**256-points**	**272,214** (9.07ms)	298,031 (**4.97ms**)	1.70	5.40

TABLE 2.2.1 - BENCHMARK OF 32-BIT CONVOLUTION: GENERIC

1st input signal	2nd input signal	Execution time (cycles) wait-state **0** *at 30MHz*	Execution time (cycles) wait-state **1** *at 60MHz*	Error: *Amplitude average ($x10^{-9}$)*	Error: *Max. amplitude ($x10^{-9}$)*
32-point	**32-points**	**28,359** (945.3us)	29,182 (**486.4us**)	0.40	1.60
	64-points	**42,572** (1.42ms)	43,788 (**729.8us**)	0.40	2.10
	128-points	**70,988** (2.37ms)	72,990 (**1.22ms**)	0.30	1.90
	256-points	**127,820** (4.26ms)	131,390 (**2.19ms**)	0.40	1.70
64-point	**64-points**	**109,179** (3.64ms)	112,334 (**1.87ms**)	0.40	1.70
	128-points	**163,968** (5.47ms)	168,678 (**2.81ms**)	0.50	1.60
	256-points	**273,536** (9.12ms)	281,350 (**4.69ms**)	0.60	2.70
128-point	**128-points**	**429,026** (14.30ms)	441,458 (**7.36ms**)	0.40	2.30
	256-points	**644,074** (21.47ms)	662,677 (**11.04ms**)	0.40	2.00
256-point	**256-points**	**1,701,554** (56.72ms)	1,750,962 (**29.18ms**)	0.50	3.10

TABLE 2.2.2 - BENCHMARK OF 32-BIT CONVOLUTION: AVR32-UC3 OPTIMIZED

1st input signal	2nd input signal	Execution time (cycles) wait-state **0** *at 30MHz*	Execution time (cycles) wait-state **1** *at 60MHz*	Error: *Amplitude average ($x10^{-9}$)*	Error: *Max. amplitude ($x10^{-9}$)*
32-point	**32-points**	**13,361** (445.4us)	13,680 (**228.0us**)	0.60	2.30
	64-points	**19,958** (665.3us)	20,414 (**340.2us**)	0.50	2.10
	128-points	**33,142** (1.10ms)	33,872 (**564.5us**)	0.50	1.90
	256-points	**59,510** (1.98ms)	60,784 (**1.01ms**)	0.50	2.10
64-point	**64-points**	**50,501** (1.68ms)	51,624 (**860.4us**)	0.50	1.70
	128-points	**75,722** (2.52ms)	77,376 (**1.29ms**)	0.60	2.40
	256-points	**126,154** (4.21ms)	128,864 (**2.15ms**)	0.70	2.70
128-point	**128-points**	**196,972** (6.57ms)	201,244 (**3.35ms**)	0.50	2.30
	256-points	**295,540** (9.85ms)	301,887 (**5.03ms**)	0.60	2.30
256-point	**256-points**	**778,684** (25.96ms)	795,388 (**13.26ms**)	0.60	3.10

TABLE 3.1.1 - BENCHMARK OF 16-BIT FIR FILTER: GENERIC

	Number of Taps	I.R.* in SRAM *(cycles)* wait-state **0** *at 30MHz*	I.R.* in SRAM *(cycles)* wait-state **1** *at 60MHz*	I.R.* in FLASH *(cycles)* wait-state **0** *at 30MHz*	I.R.* in FLASH *(cycles)* wait-state **1** *at 60MHz*	Error: *Amplitude average (x10^{-5})*	Error: *Max. amplitude (x10^{-5})*
64-point	24	**7,424** (247.5us)	7,682 (**128.0us**)	10,704 (356.8us)	12,352 (205.9us)	2.27	9.46
	48	**5,780** (192.7us)	5,996 (**99.9us**)	8,517 (283.9us)	9,868 (164.5us)	3.09	15.57
256-point	24	**41,793** (1.39ms)	43,202 (**720.0us**)	60,433 (2.01ms)	69,760 (1.16ms)	2.22	9.46
	48	**70,101** (2.34ms)	72,620 (**1.21ms**)	103,750 (3.46ms)	120,268 (2.00ms)	5.66	27.20
	72	**90,921** (3.03ms)	94,262 (**1.57ms**)	135,691 (4.52ms)	157,528 (2.63ms)	11.25	52.65
	100	**105,127** (3.50ms)	108,903 (**1.82ms**)	156,466 (5.22ms)	185,989 (3.10ms)	14.19	63.71
512-point	24	**87,617** (2.92ms)	90,562 (**1.51ms**)	126,737 (4.22ms)	146,304 (2.44ms)	2.23	9.46
	48	**155,861** (5.20ms)	161,452 (**2.69ms**)	230,726 (7.69ms)	267,468 (4.46ms)	5.78	27.20
	72	**216,617** (7.22ms)	224,566 (**3.74ms**)	323,339 (10.78ms)	375,384 (6.26ms)	10.79	52.65
	100	**276,391** (9.21ms)	286,311 (**4.77ms**)	411,442 (13.71ms)	489,093 (8.15ms)	14.05	63.71
1024-point	24	**179,265** (5.98ms)	185,282 (**3.09ms**)	259,345 (8.64ms)	299,392 (4.99ms)	2.21	9.46
	48	**327,381** (10.91ms)	339,116 (**5.65ms**)	484,678 (16.16ms)	561,868 (9.36ms)	5.85	27.20
	72	**468,009** (15.60ms)	485,174 (**8.09ms**)	698,635 (23.29ms)	811,096 (13.52ms)	10.69	52.65
	100	**618,919** (20.63ms)	641,127 (**10.69ms**)	921,394 (30.71ms)	1,095,301 (18.26ms)	13.99	63.71

*: Impulse Response.

TABLE 3.1.2 - BENCHMARK OF 16-BIT FIR FILTER: AVR32-UC3 OPTIMIZED

	Number of Taps	I.R.* in SRAM *(cycles)*		I.R.* in FLASH *(cycles)*		Error	
		wait-state		wait-state		*Amplitude average ($x10^{-5}$)*	*Max. amplitude ($x10^{-5}$)*
		0 *at 30MHz*	**1** *at 60MHz*	**0** *at 30MHz*	**1** *at 60MHz*		
64-point	24	**2,439** (81.3us)	2,657 (**44.3us**)	2,703 (90.1us)	3,054 (50.9us)	2.27	9.46
	48	**2,115** (70.5us)	2,309 (**38.5us**)	2,355 (78.5us)	2,670 (44.5us)	3.09	15.57
256-point	24	**12,712** (423.7us)	13,841 (**230.7us**)	14,128 (470.9us)	15,966 (266.1us)	2.22	9.46
	48	**21,604** (720.1us)	23,573 (**392.9us**)	24,148 (804.9us)	27,390 (456.5us)	5.66	27.20
	72	**28,192** (939.7us)	30,785 (**513.1us**)	31,576 (1.05ms)	35,862 (597.7us)	11.25	52.65
	100	**32,966** (1.10ms)	36,014 (**600.2us**)	36,966 (1.23ms)	42,015 (700.3us)	14.19	63.71
512-point	24	**26,408** (880.3us)	28,753 (**479.2us**)	29,360 (978.7us)	33,182 (553.0us)	2.23	9.46
	48	**47,588** (1.59ms)	51,925 (**865.4us**)	53,204 (1.77ms)	60,350 (1.01ms)	5.78	27.20
	72	**66,464** (2.22ms)	72,577 (**1.21ms**)	74,456 (2.48ms)	84,566 (1.41ms)	10.79	52.65
	100	**85,574** (2.85ms)	93,486 (**1.56ms**)	95,974 (3.20ms)	109,087 (1.82ms)	14.05	63.71
1024-point	24	**53,800** (1.79ms)	58,577 (**976.3us**)	59,824 (1.99ms)	67,614 (1.13ms)	2.21	9.46
	48	**99,556** (3.32ms)	108,629 (**1.81ms**)	111,316 (3.71ms)	126,270 (2.10ms)	5.85	27.20
	72	**143,008** (4.77ms)	156,161 (**2.60ms**)	160,216 (5.34ms)	181,974 (3.03ms)	10.69	52.65
	100	**190,790** (6.36ms)	208,430 (**3.47ms**)	213,990 (7.13ms)	243,231 (4.05ms)	13.99	63.71

*: Impulse Response.

TABLE 3.2.1 - BENCHMARK OF 32-BIT FIR FILTER: GENERIC

	Number of Taps	I.R.* in SRAM *(cycles)*		I.R.* in FLASH *(cycles)*		Error	
		wait-state		wait-state		*Amplitude average* $(x10^{-9})$	*Max. amplitude* $(x10^{-9})$
		0 *at 30MHz*	**1** *at 60MHz*	**0** *at 30MHz*	**1** *at 60MHz*		
64-point	24	**13,984** (466.1us)	14,365 (**239.4us**)	16,608 (553.6us)	18,624 (310.4us)	2.10	12.40
	48	**11,101** (370.0us)	11,419 (**190.3us**)	13,311 (443.7us)	14,865 (247.8us)	2.50	14.40
256-point	24	**79,073** (2.64ms)	81,181 (**1.35ms**)	93,985 (3.13ms)	105,408 (1.76ms)	2.30	17.40
	48	**135,518** (4.52ms)	139,291 (**2.32ms**)	162,688 (5.42ms)	181,713 (3.03ms)	2.70	16.60
	72	**177,131** (5.90ms)	182,137 (**3.04ms**)	213,391 (7.11ms)	238,002 (3.97ms)	4.60	31.50
	100	**187,238** (6.24ms)	194,313 (**3.24ms**)	241,717 (8.06ms)	264,808 (4.41ms)	4.60	31.90
512-point	24	**165,857** (5.53ms)	170,269 (**2.84ms**)	197,153 (6.57ms)	221,120 (3.69ms)	2.60	23.10
	48	**301,406** (10.05ms)	309,787 (**5.16ms**)	361,856 (12.06ms)	404,177 (6.74ms)	3.20	23.90
	72	**422,123** (14.07ms)	434,041 (**7.23ms**)	508,559 (16.95ms)	567,218 (9.45ms)	5.10	35.30
	100	**492,390** (16.41ms)	510,985 (**8.52ms**)	635,701 (21.19ms)	696,424 (11.61ms)	5.10	31.90
1024-point	24	**339,425** (11.31ms)	348,445 (**5.81ms**)	403,489 (13.45ms)	452,544 (7.54ms)	3.70	28.40
	48	**633,182** (21.11ms)	650,779 (**10.85ms**)	760,192 (25.34ms)	849,105 (14.15ms)	4.60	29.30
	72	**912,107** (30.40ms)	937,849 (**15.63ms**)	1,098,895 (36.63ms)	1,225,650 (20.43ms)	6.50	35.30
	100	**1,102,694** (36.76ms)	1,144,329 (**19.07ms**)	1,423,669 (47.46ms)	1,559,656 (26.00ms)	6.40	33.30

*: Impulse Response.

TABLE 3.2.2 - BENCHMARK OF 32-BIT FIR FILTER: AVR32-UC3 OPTIMIZED

	Number of Taps	I.R.* in SRAM *(cycles)*		I.R.* in FLASH *(cycles)*		Error	
		wait-state		wait-state		*Amplitude average ($x10^{-9}$)*	*Max. amplitude ($x10^{-9}$)*
		0 *at 30MHz*	**1** *at 60MHz*	**0** *at 30MHz*	**1** *at 60MHz*		
64-point	24	**6,479** (216.0us)	6,613 (**110.2us**)	9,141 (304.7us)	10,918 (182.0us)	2.10	12.40
	48	**5,132** (171.1us)	5,245 (**87.4us**)	7,305 (243.5us)	8,866 (147.8us)	2.50	14.40
256-point	24	**36,432** (1.21ms)	37,140 (**619.0us**)	51,574 (1.72ms)	61,605 (1.03ms)	2.30	12.40
	48	**62,157** (2.07ms)	63,420 (**1.06ms**)	88,906 (2.96ms)	107,937 (1.80ms)	2.70	16.60
	72	**81,114** (2.70ms)	82,788 (**1.38ms**)	116,446 (3.88ms)	142,173 (2.37ms)	4.60	31.50
	100	**94,441** (3.15ms)	96,490 (**1.61ms**)	140,910 (4.70ms)	166,671 (2.78ms)	4.60	31.90
512-point	24	**76,368** (2.55ms)	77,844 (**1.30ms**)	108,150 (3.61ms)	129,189 (2.15ms)	2.60	23.10
	48	**138,189** (4.61ms)	140,988 (**2.35ms**)	197,706 (6.59ms)	240,033 (4.00ms)	3.20	23.90
	72	**193,242** (6.44ms)	197,220 (**3.29ms**)	277,470 (9.25ms)	338,781 (5.65ms)	5.10	35.30
	100	**248,297** (8.28ms)	253,674 (**4.23ms**)	370,542 (12.35ms)	438,287 (7.30ms)	5.10	31.90
1024-point	24	**156,240** (5.21ms)	159,252 (**2.65ms**)	221,302 (7.38ms)	264,357 (4.41ms)	3.70	28.40
	48	**290,253** (9.68ms)	296,124 (**4.94ms**)	415,306 (13.84ms)	504,225 (8.40ms)	4.50	29.30
	72	**417,498** (13.92ms)	426,084 (**7.10ms**)	599,518 (19.99ms)	731,997 (12.20ms)	6.50	35.30
	100	**556,009** (18.53ms)	568,042 (**9.47ms**)	829,806 (27.66ms)	981,519 (16.36ms)	6.40	33.30

*: Impulse Response.

TABLE 4.1.1 - BENCHMARK OF 16-BIT FIR FILTER: GENERIC

	Order of the filter	Execution time *(cycles)* wait-state **0** *at 30MHz*	Execution time *(cycles)* wait-state **1** *at 60MHz*	Error: *Amplitude average (x10^{-5})*	Error: *Max. amplitude (x10^{-5})*
72-point	2	**5,294** (176.5us)	5,717 (**95.3us**)	1.50	4.00
	7	**11,469** (382.3us)	12,802 (**213.4us**)	1.40	4.30
	12	**16,319** (544.0us)	18,387 (**306.5us**)	2.50	7.60
256-point	2	**19,096** (636.5us)	20,621 (**343.7us**)	1.50	4.00
	7	**44,591** (1.49ms)	49,786 (**829.8us**)	1.40	4.30
	12	**68,761** (2.29ms)	77,451 (**1.29ms**)	3.50	8.90
512-point	2	**38,296** (1.28ms)	41,357 (**689.3us**)	1.50	4.00
	7	**90,671** (3.02ms)	101,242 (**1.69ms**)	1.40	4.30
	12	**141,721** (4.72ms)	159,627 (**2.66ms**)	3.70	8.90
1024-point	2	**76,696** (2.56ms)	82,829 (**1.38ms**)	1.50	4.00
	7	**182,831** (6.09ms)	204,154 (**3.40ms**)	1.40	4.30
	12	**287,641** (9.59ms)	323,979 (**5.40ms**)	3.90	8.90

Table 4.1.2 - Benchmark of 16-bit FIR Filter: AVR32-UC3 optimized

	Order of the filter	Execution time *(cycles)* wait-state		Error	
		0 *at 30MHz*	**1** *at 60MHz*	*Amplitude average ($x10^{-5}$)*	*Max. amplitude ($x10^{-5}$)*
72-point	2	**2,725** (90.8us)	2,871 (**47.9us**)	1.20	4.00
	7	**4,332** (144.4us)	4,682 (**78.0us**)	1.90	6.90
	12	**6,089** (203.0us)	6,534 (**108.9us**)	3.30	8.40
256-point	2	**9,167** (305.6us)	9,633 (**160.6us**)	1.10	4.00
	7	**15,006** (500.2us)	16,228 (**270.5us**)	1.70	6.90
	12	**22,283** (742.8us)	23,876 (**397.9us**)	5.10	12.40
512-point	2	**18,127** (604.2us)	19,041 (**317.4us**)	1.10	4.00
	7	**29,854** (995.1us)	32,292 (**538.2us**)	1.70	6.90
	12	**44,811** (1.49ms)	48,004 (**800.1us**)	5.60	12.40
1024-point	2	**36,047** (1.20ms)	37,857 (**631.0us**)	1.10	4.00
	7	**59,550** (1.99ms)	64,420 (**1.07ms**)	1.70	6.90
	12	**89,867** (3.00ms)	96,260 (**1.60ms**)	5.80	12.40

TABLE 4.2.2 - BENCHMARK OF 32-BIT FIR FILTER: GENERIC

	Order of the filter	Execution time *(cycles)* wait-state **0** *at 30MHz*	Execution time *(cycles)* wait-state **1** *at 60MHz*	Error: *Amplitude average ($x10^{-9}$)*	Error: *Max. amplitude ($x10^{-9}$)*
72-point	2	**7,582** (252.7us)	8,072 (**134.5us**)	1.00	3.80
	7	**14,517** (483.9us)	15,922 (**265.4us**)	1.50	7.00
	12	**19,952** (665.1us)	22,097 (**368.3us**)	2.60	10.30
256-point	2	**27,456** (915.2us)	29,232 (**487.2us**)	0.80	3.80
	7	**56,471** (1.88ms)	61,922 (**1.03ms**)	1.50	7.00
	12	**83,986** (2.80ms)	92,937 (**1.55ms**)	1.50	10.30
512-point	2	**55,104** (1.84ms)	58,672 (**977.9us**)	0.80	3.80
	7	**114,839** (3.83ms)	125,922 (**2.10ms**)	1.50	7.00
	12	**173,074** (5.77ms)	191,497 (**3.19ms**)	1.40	10.30
1024-point	2	**110,400** (3.68ms)	117,552 (**1.96ms**)	0.80	3.80
	7	**231,575** (7.72ms)	253,922 (**4.23ms**)	1.50	7.00
	12	**351,250** (11.71ms)	388,617 (**6.48ms**)	1.30	10.30

TABLE 4.2.1 - BENCHMARK OF 32-BIT FIR FILTER: AVR32-UC3 OPTIMIZED

	Order of the filter	Execution time *(cycles)*		Error	
		wait-state		*Amplitude average ($x10^{-9}$)*	*Max. amplitude ($x10^{-9}$)*
		0 *at 30MHz*	**1** *at 60MHz*		
72-point	2	**5,297** (176.6us)	5,662 (**94.4us**)	1.00	3.80
	7	**8,859** (295.3us)	9,233 (**153.9us**)	1.50	7.00
	12	**11,670** (389.0us)	12,239 (**204.0us**)	3.00	10.30
256-point	2	**18,731** (624.4us)	20,014 (**333.6us**)	0.80	3.80
	7	**33,333** (1.11ms)	34,625 (**577.1us**)	1.50	7.00
	12	**46,816** (1.56ms)	48,855 (**814.3us**)	1.80	10.30
512-point	2	**37,419** (1.25ms)	39,982 (**666.4us**)	0.80	3.80
	7	**67,381** (2.25ms)	69,953 (**1.17ms**)	1.60	7.00
	12	**95,712** (3.19ms)	99,799 (**1.66ms**)	1.70	10.30
1024-point	2	**74,795** (2.49ms)	79,918 (**1.33ms**)	0.80	3.80
	7	**135,477** (4.52ms)	140,609 (**2.34ms**)	1.60	7.00
	12	**193,504** (6.45ms)	201,687 (**3.36ms**)	1.60	10.30

6 Comparative

6.1 16-bit complex FFT

STMicroelectronics ARM9E-based STR91x

	Cycle count	at 96 MHz	at 60 MHz	at 30MHz
64-point	2,701	28.14 us	45.02 us	90.03 us
256-point	13,740	143.12 us	229.00 us	458.00 us
1024-point	68,534	713.90 us	1.14 ms	2.28 ms

Microchip dsPIC

	Cycle count	at 40 MHz	at 30 MHz
64-point	3,739	93.5 us	124.63 us
256-point	19,055	476.4 us	635.17 us

6.2 16-bit FIR Filter

STMicroelectronics ARM9E-based STR91x

STMicroelectronics uses another algorithm to compute its FIR Filter. It is not comparable because it is made to compute a signal in real-time while ours compute a whole block of data and so is not optimized the same way as ours.

Comparatively, to compute a 24-TAP filter of a signal of 64 points, ST algorithm would take approximately 1,813*(64-24+1) = 74,333 cycles, while ours takes only 2,439 cycles.

Microchip dsPIC

Contrariwise to STMicroelectronics, Microchip uses the same algorithm as ours. For the same result, it takes about 33% cycles less than ours. Indeed, the FIR algorithm is based on the "MAC" instruction and dsPIC owns a very efficient one.

In only one cycle, this instruction can read two 16-bits data from memory, update the memory pointers and perform a MAC instruction.

(cf. "Microchip dsPIC – Section 2. - Instruction Set Details" page 35)

(http://ww1.microchip.com/downloads/en/DeviceDoc/sect2.pdf)

6.3 16-bit IIR Filter

STMicroelectronics ARM9E-based STR91x

The following results are for a 4th order filter.

Number of Taps	Cycle count	at 96 MHz	at 60 MHz	at 30MHz
24-tap	2,248	23.42 us	37.47 us	74.94 us
48-tap	4,396	45.79 us	73.27 us	146.54 us
72-tap	6,544	68.16 us	109.07 us	218.14 us

Microchip dsPIC

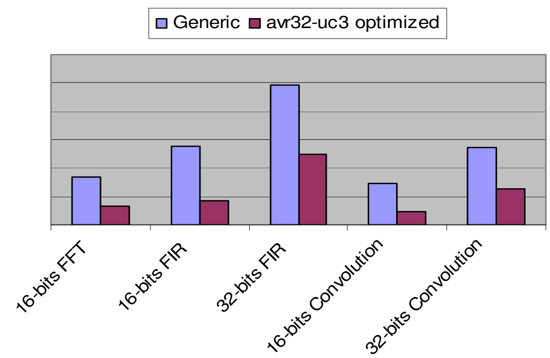
Formula: 46+N*(16+7*M) where M is the order of the filter and N the number of points to process.

Advantages of the AVR32-DSPLib compared to the others:

- It can use any fixed-point Q-Formatted numbers.
- It is compatible with any platforms that are supported by GCC and IAR.
- It can be customized with several algorithm optimization options according to your needs.

Code optimization with DSP Instructions:

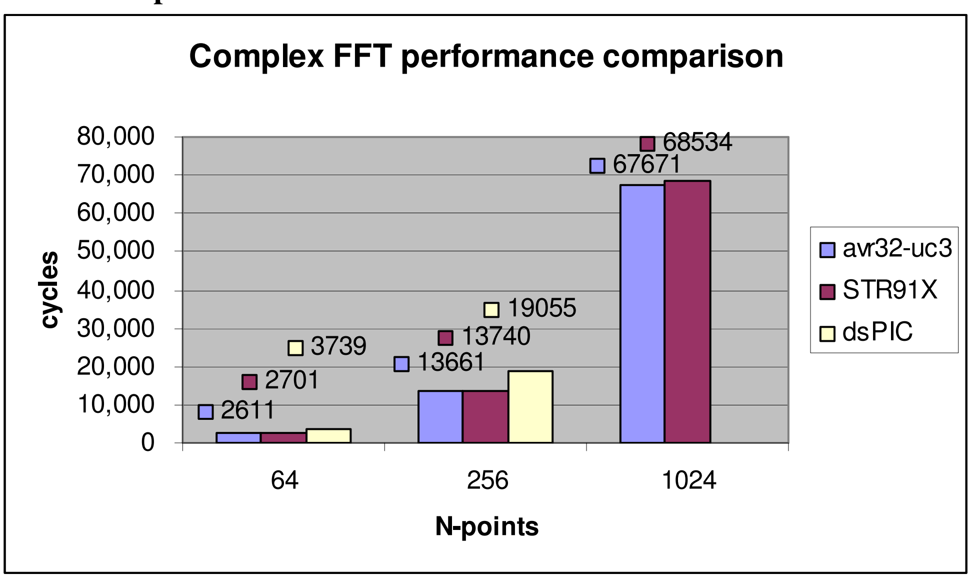
This graphics shows the difference between the code optimized with DSP Instructions for the avr32-uc3 (■ avr32 uc3 optimized) and the code without (■ generic). On the avr32-uc3, we gain from 100% to 200% of speed execution.



List of currently implemented functions:

Complex FFT, FIR filter, convolution, partial convolution, sine/cosine, sinusoidal/cosinusoidal generator, vector copy, zero padding.

Performance comparison:



IIR Filter performance comparison